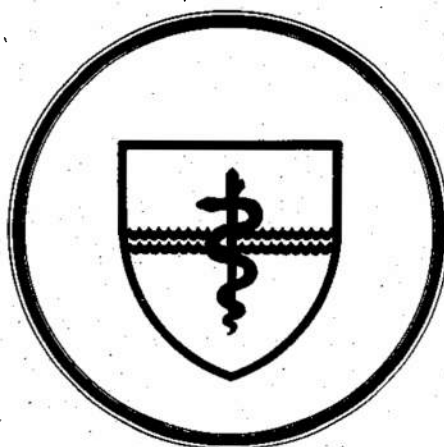


NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

SUBMARINE BASE, GROTON, CONN.



REPORT NUMBER 1015

**MANUAL PERFORMANCE IN THE COLD
WITH GLOVES AND BARE HANDS**

by

William H. Rogers and Ernest M. Noddin

**Naval Medical Research and Development Command
Research Work Unit MR041.01.06A-0003**

Released by:

**William C. Milroy, CAPT, MC, USN
Commanding Officer
Naval Submarine Medical Research Laboratory**

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MANUAL PERFORMANCE IN THE COLD WITH GLOVES AND BARE HANDS¹

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Summary.—Previous research aimed at quantifying and reducing the decrements encountered in performing manual tasks in cold weather has not described the relationships between task characteristics and cold-induced impairments. The amount of decrement and, often times, the optimal means for reducing the decrement, appear to be task-specific. The research reported here is one in a series of studies formulated to explore those relationships. The strategy is to use tasks from the battery developed by Fleishman (1967) to measure the factorially 'pure' abilities needed to perform all manual tasks. 24 U.S. Marines performed this battery of nine tasks across a range of cold temperatures. To determine if the decrement due to wearing gloves might be less than the decrement due to cold hands as the air temperature decreased, performance on the battery of tasks was measured with and without gloves. Only three of the tasks (abilities) were affected by cold temperatures, and the amount of decrement increased as the air temperature decreased. Three tasks deteriorated due to wearing of gloves, two of those affected by cold and one other. Temperature affected performance independently of the glove effect. Half of the subjects did not complete bare-handed testing at -18°C (approximately 20 min.), indicating this is the lower end of the temperature range in which bare-handed performance for more than a few minutes is practical.

The decrements in manual performance experienced in cold temperatures have long been recognized as a major contributor to the general inefficiencies encountered in military cold weather operations. A great deal of research over the last 50 years has attempted to identify, quantify, and reduce cold-induced performance decrements on manual tasks. These cold-induced manual decrements have been assessed in relation to air temperature (Horvath & Freedman, 1947; Fox, 1967), wind-chill conditions (Teichner, 1957), and hand-skin temperatures (McCleary, 1953; Clark, 1961). A common strategy has been to choose tasks similar to the operational tasks identified as being deleteriously affected by the cold. While solving the specific problem at hand, this strategy restricts the generality of results. The amount of decre-

¹This research was conducted under the Naval Medical Research and Development Command, U.S. Department of the Navy, Research Work Unit MR0410106A-003. The opinions and assertions contained in this article are those of the authors and should not be construed as official or as reflecting the views of the Department of the Navy or the Naval Submarine Medical Research Laboratory. The authors express their appreciation to the U.S. Marines of the Marine Barracks, Subase, Groton, CT, who served as subjects in this experiment, and to the staff of the Marine Barracks and the Naval Submarine Medical Research Laboratory who assisted in the conduct of this experiment. Requests for reprints should be sent to William H. Rogers, Behavioral Sciences Department, Naval Submarine Medical Research Laboratory, Box 900, Naval Submarine Base New London, Groton, CT 06349.

ment, and often times, the optimal solution for reduction of the decrement, appears to be task-specific (Fox, 1967; Vaughn, Higgins, & Funkhouser, 1968). Consequently, each time operational forces identify some task as being particularly problematic in cold weather, the research community must consult the literature to determine if it, or a similar task, has been evaluated before. If it has not, then cold temperature experiments using that task are performed.

A series of studies underway in this laboratory has been designed to address problems arising from the task-specificity of cold-induced performance decrements. Underlying this approach is the notion that all manual tasks are composed of a small, finite set of abilities which are factorially 'pure,' i.e., competence in one ability is independent of competence in any of the other abilities. It is assumed that external factors, such as cold temperatures, can affect each ability differently. Operational tasks are differentially affected by cold because the contribution of different 'pure' abilities to performance varies from task to task. Based on the work of Fleishman and his associates (Fleishman, 1967), we have adopted a battery of nine tasks which provides reasonably good measures of the 'pure' manual abilities hypothesized to be required to perform nearly all operational manual tasks.

Our goal is to identify and quantify decrements on each pure ability task across a range of cold temperatures likely to affect performance but not be a serious injury threat (e.g., -20° to 0°C). Based on the nature of the ability involved and the amount of decrement found, we then plan to investigate options for improving performance on the affected tasks. The emphasis for improvement techniques will be on procedures which can be employed rapidly, as the scenario we are concerned with is combat personnel with no cold weather training being sent to a cold weather environment and being required to be combat ready within two or three days. Finally, through a compositional analysis and empirical validations with selected operational tasks, we will determine the pure ability composition of different types of operational tasks so that future demands for quantification and reduction of cold-induced decrements on untested operational tasks can be addressed without extensive empirical test.

Rogers, Noddin, and Moeller (1982) reported findings from the initial study in this series, in which the goals were to validate the 'pure' abilities notion and provide preliminary quantification of cold-induced decrements on each of the nine pure ability tasks composing our task battery. The important findings were that correlations among performances of the various tasks were generally low, confirming the claim that the tasks were measuring separate and independent abilities and as expected, different amounts of decrement due to exposure to about -10°C were found for the different tasks, with only four tasks showing statistically reliable decrements due to cold.

The experiment reported here was undertaken to quantify cold-induced decrements on each of the pure ability tasks across a range of cold temperatures, replicate under more controlled conditions the findings of the Rogers, *et al.* (1982) study in terms of amount of decrement experienced at -10°C , and compare bare-handed and gloved performance of tasks. This latter comparison tests the common-sense notion that cold hands and gloves both generally deteriorate manual performance, and task requirements and temperature determine whether gloves or bare-hands result in the lesser performance degradation.

METHOD

Subjects

Twenty-four U.S. Marines stationed at the Marine Barracks, Subase, Groton, CT volunteered for this experiment. All were 18- to 23-yr.-old males, whose mean age was 20 yr. None had any military cold-weather training, and about half grew up in northern states; hence it was assumed they had some general cold weather experience. Six four-man replications were run, three in late spring—early summer and three in late fall.

Tasks

Each task was used to measure a different primary motor ability or psychomotor factor. The tasks and abilities measured were those described by Fleishman (1967). The specific versions of the task used here were described by Rogers, *et al.* (1982). The nine tasks and the abilities they measured are: (1) O'Connor Finger Dexterity Test, finger dexterity; (2) Minnesota Manual Dexterity Test, two-handed manual dexterity; (3) Rotary Pursuit Test, control precision; (4) Steadiness Test, arm-hand steadiness; (5) Simple Reaction Time Test, reaction time; (6) Choice Reaction Time Test, response orientation; (7) Tapping Test, arm speed; (8) Pencil and Paper Tapping Test, wrist-finger speed; and (9) Pencil and Paper Aiming Test, fine aiming ability.

Materials

Testing was done in a cold chamber located at the Naval Underwater Systems Center, New London, CT. The chamber was 4.6 m long by 3.7 m wide by 2.7 m high. Training and control tests were administered at room temperature (20°C to 27°C). A fan run as part of the cooling system produced a five miles per hour wind which was somewhat attenuated by room geometry at two of the four test stations. The average wind speed made the test temperatures equivalent to -18° , -10° , and -1°C still air temperatures in terms of cooling effect.

Hand skin temperatures (HST's) were measured by Yellow Springs Instruments surface temperature probes (No. 409a) fastened to the back of the hand and the proximal phalanx of the second and fifth fingers of each subject's non-preferred hand. Subjects wore Marine Corps standard-issue cold weather

clothing, and for the gloved condition they wore the wool insert glove liners usually worn inside leather glove or mitten shells.

The reaction time apparatus consisted of a vertical partition with a center-mounted stimulus light containing two colored bulbs, and four keys on a horizontal board, two on each side of the vertical partition. The two keys on the subject's side of the vertical partition were 4 in. (10.2 cm) apart. The RTs were measured with a Lafayette clock counter, Model No. 54417. The Rotary Pursuit (No. 30010), Minnesota Manual Dexterity Test (No. 32023), Steadiness Tester—Hole Type (No. 32011), Tapping Board (No. 32012), and O'Connor Finger Dexterity Test (No. 32021) apparatus were all off-the-shelf items from Lafayette Instrument Co. The Steadiness Tester, Rotary Pursuit and Reaction Time apparatus were connected to clock/counters and the Tapping Board was connected to a mechanical counter. Hand-held stop-watches were used to time tests with time limits.

Procedure

Each replication (four subjects) entailed three days of training and a test day (Monday through Thursday). On the first training day subjects filled out a Cold Exposure Attitude Scale (CEAS), developed at this laboratory, to assess a possible relationship between attitude and performance in the cold. Prior to actual training, subjects were also given verbal instruction, a demonstration of the proper procedure for performance of each task, and briefing on the procedures that would be used on the test day.

Tasks were performed twice bare-handed and twice with the U.S. Marine standard issue wool insert gloves on each practice day. On the test day, subjects performed the tasks a total of eight times, once with gloves and once bare-handed at room temperature and still air temperature equivalents of -18° , -10° , -1°C . The control session was always run first, after which HST probes were attached. Test temperature order was balanced across subjects and replications. Hand-state order was randomized across all subjects and sessions with the restriction that the four subjects assigned to a temperature order were counterbalanced for hand-state order at each temperature.

Tasks were performed at four test stations so that four subjects could be tested simultaneously. The order of rotation of subjects through the test stations was fixed, but the starting position for each subject changed each session. Each of the six test sessions (gloved and bare-handed at each of the three cold temperatures) were carried out in the following manner: Subjects entered the chamber as a group² and HSTs were immediately recorded. They then cold-soaked for 5 min., after which they removed all hand wear appro-

²Subjects were tested either in groups of two or four. For example, if the temperature orders used for a particular replication were -10° , -1° , -18°C and -1° , -18° , -10°C , then two subjects were tested first at -10° , then all four subjects were tested at -1° and -18°C , then two subjects were tested at -10°C .

priate to the hand-state in which they were to perform the next test session, i.e., bare-handed or with wool inserts. Subjects then cold-soaked another 8 min. to assure that HSTs were relatively stable, after which testing began. HSTs were recorded every 4 to 5 min. during the soak periods, immediately before and after testing, and after completion of two test stations. Subjects were required to leave the chamber or don their gloves if any HST reached 3°C. Subjects left the chamber as a group as soon as the final HSTs were recorded.

Each session, including the soak periods and testing, took approximately 25 to 30 min. It was assumed that with this short exposure time and the clothing worn there would be no change in core temperature: a longer and colder exposure (Rogers, *et al.*, 1982) produced insignificantly small changes in core temperature with comparable clothing. Subjects were unanimous in reporting no cold discomfort except for cold hands in any exposure. Inter-session intervals were approximately 20 minutes, but no session started until all subjects' HSTs had risen to at least 27°C.

RESULTS

As a further check of the pure ability notion, a matrix of the correlations among bare-handed scores on the nine tasks at room temperature on the test day was computed (see Table 1). While hand-state order and task order could spuriously affect these correlations, simple analyses of variance gave no evidence that either variable affected control performance of any task. Five of the 36 correlations of the matrix reached significance ($p < .05$). One of those, the correlation between finger dexterity and manual dexterity, repeated a significant relationship obtained in the Rogers, *et al.* (1982) study. Choice RT was one element of the other four statistically reliable correlations found here.

TABLE 1
CORRELATIONS AMONG NINE MANUAL TASKS PERFORMED AT ROOM
TEMPERATURE ON THE TEST DAY ($N = 24$)

	1	2	3	4	5	6	7	8	9
1. O'Connor Finger Dexterity		.60†	.15	.00	.24	-.19	.02	.18	-.18
2. Minnesota Rate of Manipulation			.28	-.18	.01	-.40*	-.02	.15	-.08
3. Rotary Pursuit				-.38	-.22	-.17	.38	.10	.06
4. Steadiness					.01	.18	-.17	-.39	.01
5. Simple RT						.41*	-.35	.12	-.35
6. Choice RT							-.10	-.46*	-.47*
7. Tapping								.19	.07
8. Paper & Pencil Tapping									.31
9. Paper & Pencil Aiming									

† $p < .01$. * $p < .05$.

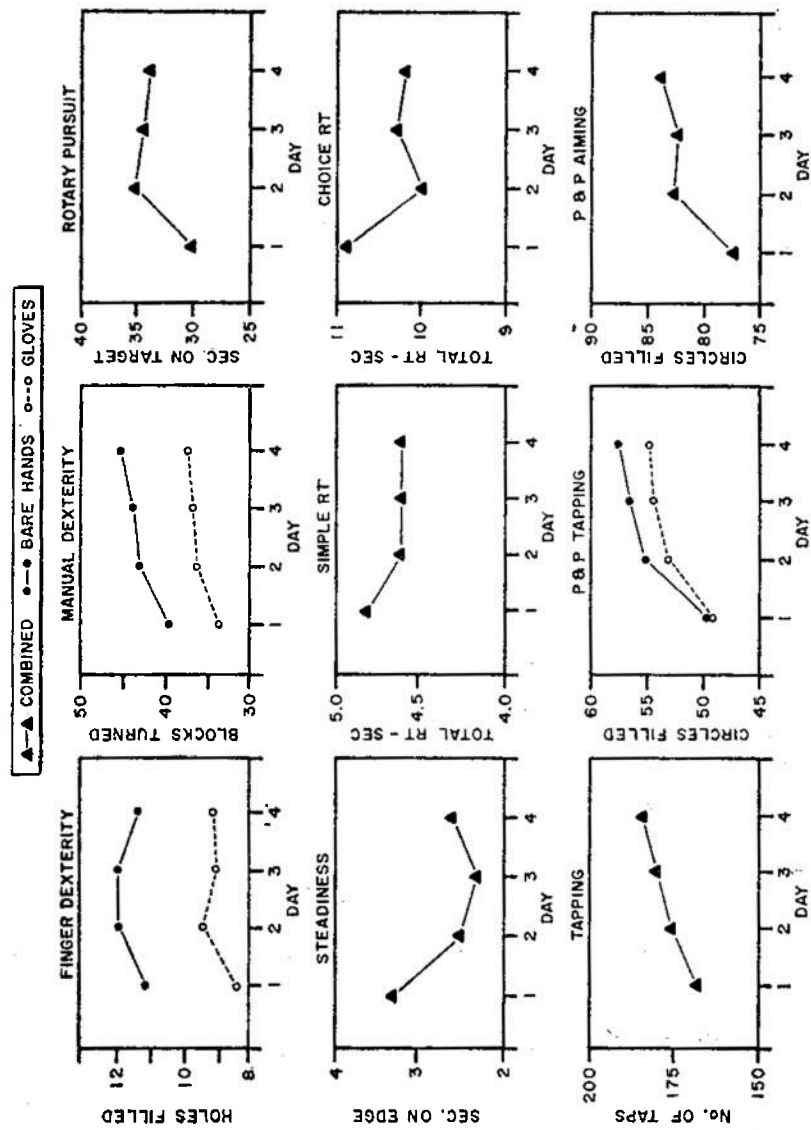


FIG. 1. Mean performance at room temperature on practice (Days 1—3) and test (Day 4) days. Bare-hands and Glove data combined for tasks showing no hand-state effect

Analyses of variance were computed on practice performance data to determine the effect of time of year, replication (between-subject), practice and hand-state (within-subject) on performance. The important findings were that: (1) all tasks improved with practice ($p < .05$); (2) the Finger Dexterity, Manual Dexterity, and Pencil and Paper Tapping tests were the only tasks deleteriously affected by the wearing of gloves ($p < .05$); and (3) there were no main effects or meaningful interactions involving time of year or replication. Mean performance for each task on each practice day and at room temperature on the test day are shown in Fig. 1. Bare-handed and gloved performance are plotted separately for the three tasks for which there was a hand-state effect. For the Steadiness, Simple and Choice Reaction Time Tests, lower scores reflected better performance.

On the test day, 22 of the 24 subjects completed the -10°C bare-handed test condition; one subject de-volunteered and another was required to put on his gloves because his HST dropped to 3°C before completion of testing. Only 12 of the 24 subjects completed all testing in the bare-handed condition at -18°C ; three de-volunteered, two put on their gloves on their own volition, and seven were required to don their gloves because their HSTs dropped to 3°C . Consequently, parametric statistical analyses excluded the -18°C data and were computed on the data from 22 subjects completing the -10°C session.

A separate analysis of variance was computed for each task. The analyses included hand-state (bare-handed versus gloved) and temperature (room, -1° , -10°C) as within-subject variables, and time of year (spring-summer versus fall) as a between-subject variable. The significant results were that: (1) Finger Dexterity, Manual Dexterity and Pencil and Paper Tapping were deleteriously affected ($p < .005$) by wearing gloves, duplicating the practice results; (2) the Finger Dexterity, Manual Dexterity and Steadiness tests were significantly degraded ($p < .001$) by the cold; and (3) the spring-summer group was significantly steadier ($p < .05$) than the fall group on the Steadiness test.

It is evident from Fig. 2, which shows mean performance for each hand-state and temperature for the four tasks affected by either variable, that performance generally deteriorated as the temperature decreased for Finger Dexterity, Manual Dexterity and Steadiness (a lower score reflected better performance on the Steadiness test). Newman-Keuls tests showed that (1) for the Steadiness and Finger Dexterity tests, room temperature and -1°C performances were significantly better than -10°C performance ($p < .01$) and (2) for the Finger Dexterity and Manual Dexterity tests, room temperature performance was better than performance at either cold temperature ($p < .01$).

To determine the relationship among attitude scores, HSTs, and cold-

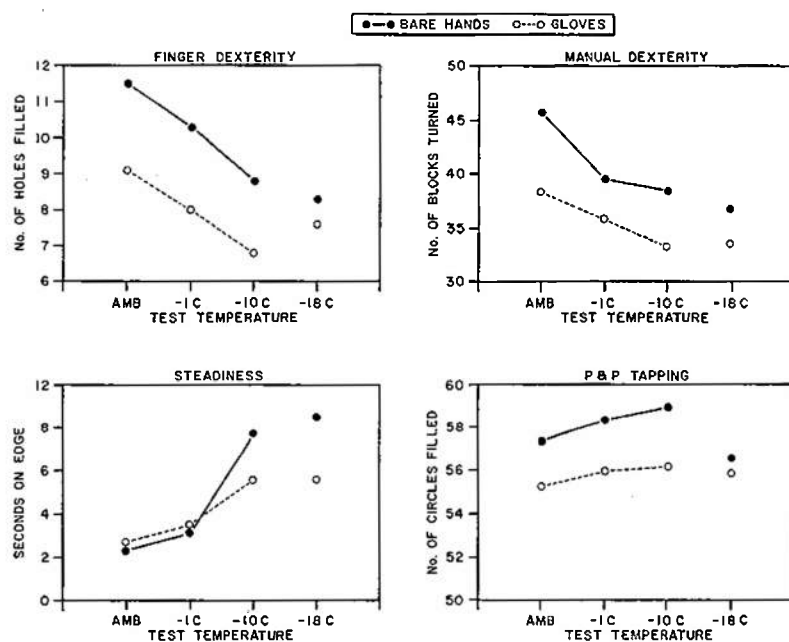


FIG. 2. Bare-handed and gloved performance at ambient (AMB) and cold temperatures on the Finger Dexterity, Manual Dexterity, Steadiness, and Pencil and Paper Tapping tasks ($N = 22$ except for the -18°C data, for which $n = 12$.)

induced performance decrements, correlations were computed among scores on the Cold Exposure Attitude Scale, index finger temperatures at completion of -10°C bare-handed testing, and -10°C bare-handed performance scores. Partial correlations, used to evaluate the relationships involving cold performance scores while taking into account control scores, were computed for the three tasks which showed significant deterioration due to the cold. The -10°C bare-handed session was used since this was the most severe cold condition which was completed by almost all subjects. The attitude scale scores showed no relationship with HSTs or cold performance measures. While index finger temperatures did systematically decrease with air temperature (see Fig. 3), and the partial correlations between index finger temperatures and -10°C scores on all three tasks were in the expected direction, none of the partial correlations reached significance at the $p < .05$ level.

DISCUSSION

The small number (five) of significant inter-task correlations found in this study further supports the notion that independent abilities are being tapped by this battery of tasks. The significant correlation between the Finger Dex-

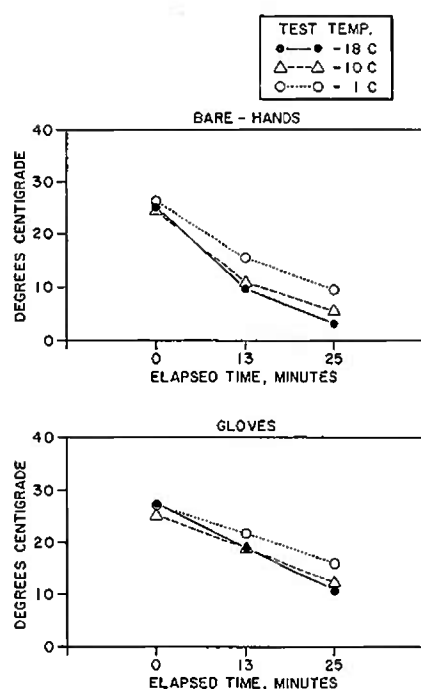


FIG. 3. Index finger temperatures recorded at 0, 13, and 25 min. into chamber exposure for bare-hand and glove conditions

terity and Manual Dexterity tasks noted in this study and in the Rogers, *et al.* (1982) and Fleishman (1954) studies indicates that a common ability contributes to performance of both tasks, or one or both tasks tap both finger and manual dexterity. The basis of the high correlations between these tasks needs further exploration. There is no obvious reason for the multiple significant correlations involving Choice RT; none of the earlier studies produced comparable results.

The better performance of the spring-summer group on the Steadiness task was unanticipated. Time of year was expected to favor the late fall group since these subjects had several weeks exposure to cold temperatures outside. Since the time of year effect occurred for only one task and was not critical to the main findings of this study, it was not further explored. The practice effects noted for all tasks were expected, and it is evident from Fig. 1 that, for the most part, performance was at or approaching asymptote on the test day.

The effect of hand-state found for the Finger Dexterity, Manual Dexterity, and Pencil and Paper Tapping tasks in both sets of analyses provides strong evidence that these tasks and the abilities they measure are deleteriously affected by wearing gloves. Gloves affect performance of these tasks independently of temperature (see Fig. 2), i.e., temperature affects bare-handed and gloved

performance comparably, so there is no gloved-hand, bare-handed performance trade-off as the temperature decreases from 0°C to -10°C. Although -18°C data were not statistically analyzed, it is apparent from inspection of Fig. 2 that the glove decrements might decrease at -18°C, and there might even be a glove advantage for the Steadiness test.

Temperature significantly affected only the Finger Dexterity, Manual Dexterity, and Steadiness tests (see Fig. 2) at the temperatures evaluated. The Newman-Keuls tests confirmed that performance generally deteriorated as the temperature decreased, with the best performance being at room temperature and the worst performance being at -10°C for all three tasks. The finding that these tasks are significantly affected at -10°C repeats the findings of the Rogers, *et al.* (1982) study. That study also found that the Rotary Pursuit task was deleteriously affected by the cold, which was not the case here. The effect of cold on the Rotary Pursuit task in this study was marginally significant ($p < .10$) at -10°C, so the difference between the two studies is small.

The practical significance of the effects of temperature and hand-state in this experiment must be considered in combination with the cold-injury threat posed by bare-handed performance. The fact that one-half of the subjects in this experiment were not able to withstand -18°C with bare hands for 20 min. suggests that bare-handed performance requiring considerable time should not be attempted at this temperature or lower without warm-up periods. Gloved performance at this temperature is generally safe and this might weigh more heavily than the small performance decrements that might result from wearing gloves.

Performances of the Rotary Pursuit, Steadiness, Simple and Choice Reaction Time, Tapping, and Pencil and Paper Aiming tests were unaffected by gloves in this study. The results indicate that they and other tasks using the same abilities should always be performed with at least wool liners on in the cold, since the wool liners do not degrade performance in relation to bare-hands, and they offer cold-injury protection. The Steadiness test and other tasks requiring arm-hand steadiness will still be degraded by the cold in comparison to control performance however. For tasks requiring finger dexterity, manual dexterity and wrist-finger speed (Pencil and Paper Tapping), performance in the cold is better bare-handed than gloved, at least to -10°C. The decision to wear gloves or not for finger dexterity, manual dexterity, and wrist-finger speed tasks would depend on the criticality of the task: Since performance will be worse with gloves than with bare hands, a particularly critical task might be performed bare-handed to minimize the decrement even though this poses more of an injury threat. If the task is not critical, the additional decrement created by the wearing of gloves might be tolerated so that the cold-

injury threat can be reduced. Tasks requiring these abilities should be further studied to find alternative methods of reducing performance decrements and cold-injury probability simultaneously.

The Cold Exposure Attitude Scale was a pilot attempt to assess the effect of attitudinal factors on cold performance. While this survey did not prove useful in this study, we believe that attitudinal factors are important in cold weather performance and refinement of the survey will be pursued.

Earlier studies (see Provins & Clarke, 1960) have yielded significant correlations between HSTs and performance in the cold. In this study, index finger temperatures steadily decreased as the air temperature decreased but did not reliably correlate with bare-handed -10°C performance scores on the tasks deleteriously affected by the cold. The lack of reliable HST-cold performance relationships and the fact that subjects showed no deterioration on many tasks with HSTs below critical levels defined by others (Provins & Clarke, 1960), accentuates several commonly overlooked factors affecting HST-cold performance relationships: (1) task demands (manual abilities required), (2) individual differences in peripheral cooling, and (3) individual differences in the ability to perform with comparable HSTs (possibly associated with attitudinal factors). While task demands are being investigated here, individual differences in HSTs and the ability to perform at comparable HSTs are generally underemphasized in cold research and need further exploration.

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